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Fossil Freshwater Microplankton (Dinoflagellates and Acritarchs) from Flandrian (Holocene) Sediments of Victoria and Western Australia

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Abstract

The history of study of living and fossil non-marine dinoflagellates is summarized. Assemblages of dinoflagellate cysts from Flandrian (Holocene) lake sediments in Victoria are described for the first time; and assemblages of dinoflagellate cysts and acritarchs from the Flandrian (Holocene) of Western Australia are reconsidered in the light of present knowledge. Three new genera of dinoflagellate cysts (*Cobricosphaeridium*, *Aquadulcum* and *Muiradinium*) are proposed and four new species described: in addition, a new acritarch genus (*Creberlumectum*) is proposed.

Introduction

In 1963, an account of assemblages of Flandrian freshwater dinoflagellates and 'hystrichospheres' was published by David M. Churchill and one of the authors (W.A.S.S.): this was the first extended account of a non-marine assemblage of these groups of plankton. Since that time, our knowledge of the character and morphology of these groups of organisms has grown enormously: in particular, the significance of openings in the shell wall (archaeopyles) in distinguishing dinoflagellate cysts from what are now termed acritarchs has come to be recognized. A re-study of the type material is here presented, together with an account of new observations on dinoflagellate cyst assemblages from a Flandrian lake sediment of Victoria.

History of Research

Serious work into the study of dinoflagellates began with the publication of research by Baker in 1753. In a chapter of a book, *'Employment for the Microscope'*, he described and discussed the phosphorescent properties of a form now known as *Noctiluca*. A little later Müller (1773) became the first to name and describe a dinoflagellate species. It was, however, not until 1838 that Ehrenberg published the first record of a fossil form. The subsequent development and history of this particular branch of dinoflagellate study is well documented (Sarjeant and Downie 1966, and Sarjeant 1967).

A. J. Schilling was the author of the first monograph dealing with freshwater peridineans (1891). Although some work had been done previously the findings were lodged in various obscure publications to which it was difficult to gain access. Schilling was the first to make a compilation of this accumulated literature and

to bring it under one cover together with his own research, thus giving a firm foundation for future work.

In subsequent years Schilling's groundwork was augmented by Lemmermann, who published a number of papers, 1900-1910. During the next twenty years a number of workers became active in this field; notable among these were Woloszynska in Poland, Lindemann in Germany and Kofoid in America. The latter dealt mainly with marine forms, but his general approach, including his morphological nomenclature, was soon adopted by the freshwater workers. Up until, and including, this period, all research was virtually confined to Europe with the exception of Kofoid (above), and Prescott (1928) and Playfair (1912), who contributed from America and Australia respectively. Schilling published a last comprehensive account of the dinoflagellates in 1913, as part of Pascher's tome *'Die Süsswasserflora Deutschlands, Osterreichs und der Schweiz'*. It should also be pointed out that at this time much basic work was being done in Europe into the study of algae in general. The present writers will confine their attention to workers concerned mainly with the study of freshwater dinoflagellates.

G. S. West was one of the first British workers to enter this particular study. He began publishing in the early 1900's; in 1905 he produced a paper with W. West on British lake plankton, and a year later a major work on the plankton populations collected from Lakes Nyasa, Victoria Nyanza and Tanganyika in Africa was published by the Linnean Society. In both papers there is a section devoted to the dinoflagellates. His third paper, published 1909, concerned a more parochial study, exclusively on dinoflagellates, which he had carried out at Sutton Park, Warwickshire. In this paper he lists seven species and discusses their periodicity, correlating it with temperature. His book *'Algae'* was published in 1916 and in this he devotes a chapter to the Peridineae, discussing their physiology and life histories. He writes of both marine and freshwater forms but goes on to list six species that may be found in a freshwater environment.

An important publication is that of Eddy (1930). He reviews all the relevant literature to date and monographs all the freshwater species, with particular reference to U.S.A.; in all he lists and describes some fifty-five species. T. M. Harris, of the University of Reading, England, contributed to our knowledge by publishing a paper in 1939 describing various species he had observed 'within a few miles of Reading'; he found a distinction between species inhabiting ponds on arable/grazing land and those from ponds on heath land.

During the next ten years two important papers were written by R. H. Thompson, in U.S.A. His first paper (1947) describes twenty species of freshwater dinoflagellates collected from small, shallow, eutrophic ponds situated on the coastal plain of Maryland; of these twenty species, two are new and ten are newly reported from America. Most of the latter are of the unarmored type. In a second paper (1950), he describes forms collected from both Maryland and Kansas. He lists twenty-two species, erects the new genus *Woloszynskia* in honour of the Polish worker, and creates five new species. In these two papers Thompson contributes much to the knowledge of freshwater forms in U.S.A.

'Freshwater Algae of the United States' by G. M. Smith first appeared in 1933, and was revised, 1960. In this text a chapter is devoted to the pyrrhophyta; a clear account of their biology is given and relevant literature reviewed. He gives descriptions of ten genera known to that date in U.S.A., and also adds notes on various species recorded.

Not a great deal of work was done in this field during the next ten years. Cridland (1957) described a new freshwater species that had been collected from

a pond near Reading, Berkshire, England; and Bursa (1958) described a new species of reticulate freshwater dinoflagellate, giving extensive consideration to its physiology. A further new freshwater species from Berkshire was reported by Mapletoft et al. (1966).

A valuable synopsis of knowledge of freshwater dinoflagellates is given by Hutchinson (1967) in '*A Treatise on Limnology: II. Introduction to lake biology and limnology*'. Four genera of the Gymnodiniales and eight genera of the Peridiniales are noted as occurring in lakes: the available information on nutrition and relation to conditions of water chemistry is reviewed.

The earliest published figure of a fossil non-marine dinoflagellate cyst is perhaps to be found in Bradley's account (1931) of the microfossils of the Green River oil shales of Colorado and Utah, U.S.A. This paper (Pl. 23, fig. 4) shows a form described as a 'zygospore, possibly of a Desmid', which closely resembles a chorate dinoflagellate cyst.

In 1942 Thiergart figured a 'hystrichosphere' from Miocene lignites of Germany. Dr. Thiergart courteously sent over his type specimen for study to one of the authors (W.A.S.S.), but the specimen indicated was found to bear little relation to Thiergart's figure (1942, Fig. 3), nor could any similar specimen be located elsewhere on the slide. The specimen marked was of uncertain character and affinity.

In 1953, Isabel Cookson described and figured a 'hystrichosphere' (which she named *Hystrichosphaeridium* cf. *hirsutum* Ehr. emend. Deflandre) from a deposit of Tertiary freshwater clay from Victoria. The author considered it possible that this was a reworked form.

In 1955, the first unquestionable record of a fossil freshwater dinoflagellate was published by Traverse, in an account of the palynology of the Oligocene Brandon Lignite of Vermont, U.S.A. This he named *Peridinium hansonianum:* there can be little question that it is, in fact, a cyst. During the same year, Leonard reported an abundant flora of hystrichospheres in a fluvial clay of Middle or Late Quaternary age from Italy. Suspecting that this might be derived, Leonard analysed the assemblages of the local Eocene, Miocene and Pliocene strata: only the Eocene yielded an assemblage, however, and that proved of dissimilar character. Insufficient detail of Leonard's assemblage has been published for any firm judgement to be made as to whether it was indeed non-marine.

In 1957, the presence of fossil dinoflagellates in a Lower Miocene pollen flora from non-marine sediments of Upper Silesia, Poland, was noted by Mackó: the fossil forms were attributed to a living species, *Glenodinium smreczyniense* Woloszynska. (This attribution must be considered questionable.)

In 1959, W. F. Harris mentioned the presence of 'tests and statoblasts of dinoflagellates' in an account of the pollen assemblages of Mangaroa Swamp, near Wellington, New Zealand (Quaternary).

In 1960, D. M. Churchill mentioned hystrichospheres in a preliminary note on non-marine assemblages from Southwest Australia, figuring (as an alga of the Cyanophyceae) a dinoflagellate cyst. These assemblages were subsequently described at length by Churchill and Sarjeant (1962, 1963): they include six species of dinoflagellates (one of which was not then recognized as such) and at least five species of acritarchs. The authors considered that these forms were freshwater and dismissed the possibility that they could be reworked. Their conclusions were attacked by Varma (1964): Churchill's reply to Varma's comments is given below (p. 215).

In 1962, Krutzsch described an assemblage of dinoflagellates from the Geiseltal

lignites of south Germany (Eocene). These were allocated to two genera of what are now considered cavate dinoflagellate cysts—*Deflandrea* and a new genus, *Geiselodinium*. Despite certain strong resemblances to Tertiary marine species, it is probable that this is indeed a non-marine assemblage.

In 1965, Eisenack and Fries published a paper in which fossil dinoflagellates from U.S. Quaternary lake sediments, regarded by the authors as fossil motile forms attributable to the species *Peridinium limbatum*, were compared with the Tertiary species *Deflandrea phosphoritica*. However, a re-study of their materials, accompanied by study of the living plankton in the lake from which their sediments were obtained, has demonstrated beyond question that these were the cysts, and not the motile forms, of *Peridinium limbatum* (Evitt and Wall, 1968). G. Norris (pers. comm.) independently came to the same conclusions.

Further work on non-marine dinoflagellate cysts from Quaternary sediments, by Evitt, Norris and Wall, is currently in progress.

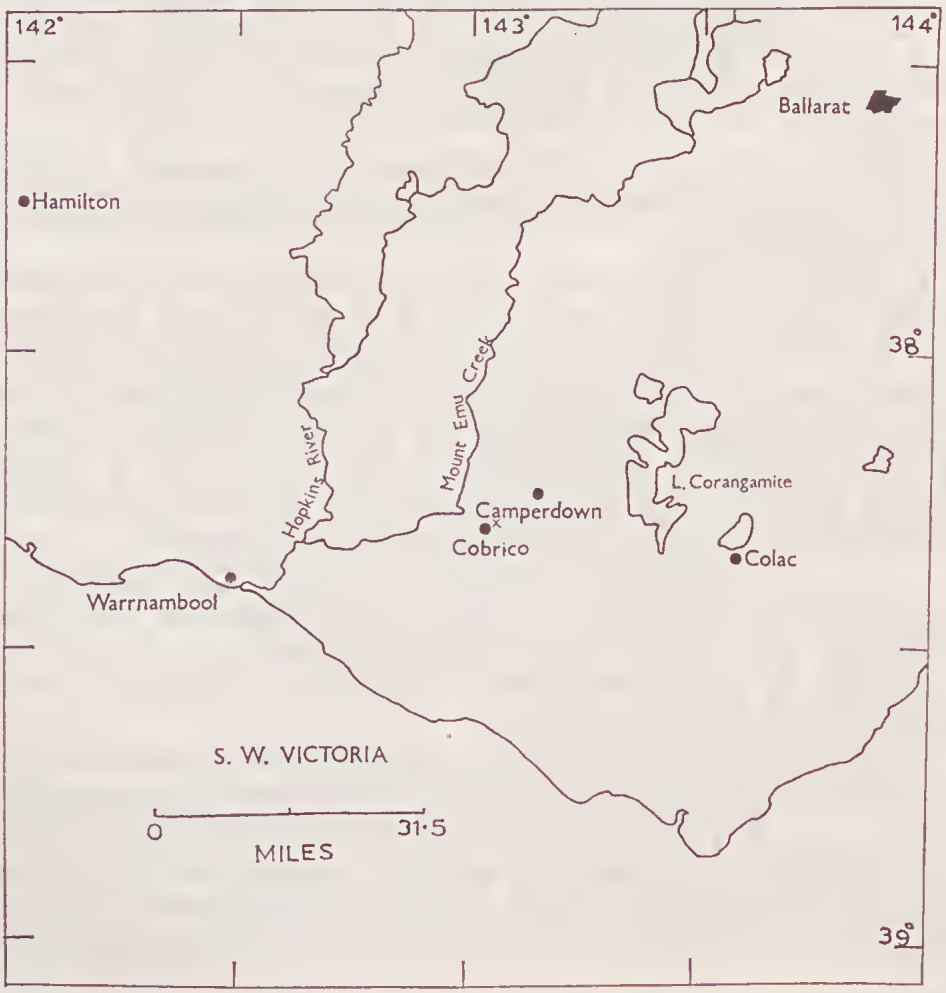

FIG. 1—Sketch Map of S.W. Victoria, showing the position of Cobrico Swamp.

Apart from the mention of acritarchs (as 'hystrichospheres') in the work of Churchill and Sarjeant (1962, 1963), there has been only one other record of their occurrence in non-marine deposits. This was by Sarjeant and Strachan (1968), who recorded two species of very small acritarchs (attributed to the genera *Micrhystridium* and *Leiosphaeridia*) in deposits in a Pleistocene 'kettle-hole' in the English Midlands.

Stratigraphy of the Victorian Lake Deposit

During investigations into the stratigraphy and vegetational history of the western lakes district of Victoria, Dr. D. M. Churchill and co-workers found several specimens of freshwater microplankton. These were forwarded to one of the authors (R.H.).

The plankton had been recovered from Cobrico Swamp, and were preserved in a freshwater peat deposit. Cobrico Swamp lies a short distance north of the township of Cobrico at Lat. 38° 18′ S., Long. 143° 02′ E. (Fig. 1). The peat was sampled to a depth of 400 cm., and the distribution of microplankton within the deposit is discussed later. The age of the deposit is Holocene (Flandrian), with a radiocarbon date from the lowermost horizons (350-400 cm) of *c.* 5,630 years B.C.

Stratigraphy of the Western Australian Non-marine Deposits

A detailed account of the localities in Southwest Australia has already been published (Churchill and Sarjeant, 1962, pp. 30-33) and need not be repeated here. The authors presented reasons for dismissing the possibility that the assemblages were reworked (p. 51) and concluded that these were indeed fossil non-marine microplankton. Their conclusions were attacked by C. P. Varma (1964). A reply to Varma's article has been prepared by Dr. D. M. Churchill and is quoted below, with his permission:—

C. P. Varma (1964, *Grana Palynologica* 5: 1: 124-128 'Do dinoflagellates and hystrichosphaerids occur in freshwater sediments?') has called into question the evidence of Churchill and Sarjeant, 1962, for the occurrence of such organisms in freshwater sediments. He states that the implications of such an occurrence could have a profound bearing on the palaeoecological interpretation of older sediments in which only these organisms were found.

The approach adopted by Varma underlines the lack of communication and understanding between people working with Tertiary and older sediments, and Quaternary workers, many of whom are studying environments in which sedimentation, life, death and fossilization of plants and animals are still taking place.

It appears that Varma is not even aware of the meaning of the term Holocene, for he states on page 126, lines 17-18, 'since the age of the deposit is Holocene, the beds are likely to have been receptive to contamination for a few million years.'

Now the term 'Holocene' (Greek *holos*, whole; *kainos*, recent) is literally 'wholly modern'. F. E. Zeuner (1958), in his book *Dating the Past*, states that this period may be taken as having lasted 10,000 to 20,000 years, according to how it is delimited from the Pleistocene. H. Godwin (1966: Introductory address, Royal Meteorological Society Symposium on World Climate from 8,000 to 0 B.C.) draws attention to the correspondence between varve chronology of glacial retreat and the radiocarbon dating of the Pleistocene-Holocene boundary, defined by pollen zonation, at about 10,300 B.C. Even ignorance of Quaternary stratigraphic nomenclature would not have led to age anomalies, however, if Varma was cognizant of the radiocarbon ages referred to in our text; and this in turn would have avoided his ridiculous suggestion of a 200-metre Holocene rise in relative sea level, onto a Pre-Cambrian land mass. The author may have been unaware of the controversy among Quaternary geologists (R. J. Russell, 1963: Recent recession of tropical cliffy coasts. *Science*, 139, 9-15; R. W. Fairbridge, 1958; *Trans. N.Y. Acad. Sci.*, 20, 471) as to whether sea-level was higher than even 10 feet above the present level. Indeed, at the time the Australian sediments, with their cysts and acritarchs, were forming in these inland and near-present-coastal lakes,

sea-level was either at or well below its present level along that part of the Australian coast where the eustatic rise has been measured.

The pertinent questions raised by Varma concern only the identification, in situ occurrence, possibilities of reworking and laboratory contamination of the microplankton described from Western Australia, and whether or not the environments in which they were found were truly freshwater.

The environments of deposition have been described in sufficient detail in our original paper. It need only be restated here that the sediments were organic, the decomposed residues of the freshwater aquatic plants growing in and around the water's edge. There were no foraminifera present at any of the sites and no vestige of evidence of marine incursions. There were no marine sediments nearby or within the watershed areas of these swamps. Accumulation of freshwater plant residues has proceeded uninterruptedly at each of the sites, with the exception of those truncated by fire(the evidence of which is left as fragments of charcoal and sand). In short, the deposits are not marine in origin and contain no marine fossils washed in from around the bogs.

The principle established by the authors in 1960 and 1962 was simply that, from then on, it became essential to fully identify the phytoplankton present before making generalized deductions about the freshwater or marine origin of the sediments.

To Dr. Churchill's comments, it is necessary only to add that none of the forms recorded from the Australian freshwater sediments has yet been recorded from a marine deposit or from the living marine plankton: the possibility of pollution in the laboratory can thus also be entirely ruled out.

Systematics

All holotypes of species from Victoria, here described, are lodged in the palynological collections of the Department of Geology, University of Alberta, Edmonton. Co-ordinates given are for use with Leitz Microscope 595949; but the holotypes are, in addition, ringed and labelled.

The holotypes and figured specimens described by Churchill and Sarjeant (1963), originally lodged at Cambridge, are now lodged in the collections of the National Museum of Victoria, Melbourne, Australia: the specimens are ringed and named. The holotypes and figured specimens were courteously loaned to one of the authors (W.A.S.S.) by Dr. D. M. Churchill for study before lodgement in the museum: but it was unfortunately not possible to borrow for study the whole of the type material.

Division Pyrrhophyta Pascher
Sub-class Diniferophycidae Bergh
Cyst-Family Uncertain

Genus **Cobricosphaeridium** gen. nov.

Derivation of Name: Named from the sample locality at Cobrico Swamp, Victoria, Australia.

Diagnosis: Spherical to sub-spherical proximochorate cysts, bearing two distinct process types. Processes of the first type are relatively long, up to a quarter of the cyst diameter, of very variable form, slender, tapering to cylindrical, erect or sinuous, wart-like, evexate to digitate and foliate, occasionally forked at their tips; bases of processes usually ornamented with granules. Processes of the second type are short, slender, cylindrical and may also be forked at their distal extremities. These processes are approximately one-half to one-sixth the length of the first type, so that distinguishing between these two process types is always readily possible. Cingulum and sulcus are present, but not often clearly defined: tabulation is otherwise absent. Archaeopyle apical (A in terms of the symbols proposed by Evitt, 1967).

TYPE SPECIES: *Cobricosphaeridium hebes* sp. nov., Holocene; Victoria, Australia.

REMARKS: This genus is erected to accommodate sub-spherical dinoflagellate cysts that exhibit two distinct process types. One type is conspicuous, the other obvious only under an oil immersion objective. Many of the longer processes appear to be either gonal or intratabular in position, but no overall pattern could be discerned. The processes are solid, do not connect to the interior of the cyst and are closed distally. This genus is similar to *Tenua* Eisenack emend. Sarjeant in all respects apart from ornamentation; in no case is the simultaneous possession of two distinct process types described from any of the species attributed to the latter genus. *Cobricosphaeridium* is also similar to *Cleistosphaeridium* Davey, Downie, Sarjeant and Williams, 1966, but again the distinctive ornamentation and the overall cyst form differentiates the two.

The extent to which the unusual habitat (freshwater sediments) distinguishes this genus can only be surmised at present.

Cobricosphaeridium hebes sp. nov.

(Pl. 21, fig. 1-2. Fig. 2)

DERIVATION OF NAME: L.: *hebes,* blunt, with reference to the nature of the larger processes.

DIAGNOSIS: Spherical to sub-spherical proximate cyst, ornamented with granules and bearing two types of processes. Processes of the first type are relatively short, wart-like, digitate to foliate, sometimes stellate in plan. Processes of the second type are even shorter than the first, slender and not easily seen. Sulcus and cingulum are poorly defined. Archaeopyle apical ($\bar{A}$) with a well-marked sulcal notch.

HOLOTYPE: Slide L.C.V./6b at 94.4-32-6, Palynological Collection of the Department of Geology, University of Alberta, Edmonton, Canada.

LOCALITY AND HORIZON: Cobrico Swamp, Victoria, Australia; Holocene.

DIMENSIONS: Holotype: Length 46μ, breadth 46μ, length of longer processes 3μ, length of shorter processes 1μ. Range: Length 42 (47·5) 55μ, breadth 34 (44·5) 53μ, longer processes range in length from 2 (3·3) 5μ; smaller processes range from less than 1μ to 1μ. (In all cases, the figure in parenthesis is the arithmetic mean.) Nine specimens were measured; these make up the total available material.

DESCRIPTION: Cyst spherical to sub-spherical, made up of two body layers. The periphragm gives rise to both granules and processes. The body wall has a total thickness in the order of 1μ. The first type of processes are short, blunt, wart-like, digitate to foliate, sometimes stellate in plan; they appear to be solid and not to connect to the interior of the cyst. They are sparsely ornamented with granules. In some cases the processes are made up from the convergence of a number of radiating ridges, giving rise to a complex stellate arrangement. Ten processes may be counted around the periphery of the holotype. Process arrangement on the central body appears irregular: no tabulation has been deciphered. The shorter processes are not very easily distinguishable but can be seen to be short, solid, slender and distally closed. Sulcus and cingulum may be seen only with difficulty, but in one or two cases they are distinguished by an alignment of the longer processes, and a slight reduction in the granular ornament. The archaeopyle is apical, apparently formed by the loss of the equivalents of two or four

apical plates. Its margin is zig-zag and a number of slits were observed to extend posteriorly from the angles.

Remarks: This species is quite well represented in the assemblages; the individual specimens are well preserved and show the nature of the archaeopyle very clearly. It was therefore chosen as type species for the genus. *Cobricosphaeridium hebes* sp. nov. is characterized by process form, the granular nature of the central body and by the archaeopyle. It resembles Organism No. 2 of Churchill and Sarjeant (1963, p. 50, Figs. 8, 35), especially in the similarity of the process type, but differs in the nature of the archaeopyle.

Cobricosphaeridium spiniferum sp. nov.

Cobricosphaeridium spiniferum spiniferum subsp. nov.

(Pl. 21, figs. 3, 6. Fig. 3)

Derivation of Name: L.: *spiniferum,* thornbearing, with respect to the general appearance of the cyst.

Diagnosis: A *Cobricosphaeridium* having a sub-spherical central body bearing two types of processes. The first are long, approximately one-quarter of the cyst diameter, slender, tapering to cylindrical; they may be erect or curved, with their distal extremities cvexate to digitate and foliate, occasionally forked. The base and shank of each process is ornamented with granules. The processes of the second type are short, approximately one-tenth of the cyst diameter, erect, cylindrical, slender and also may be forked at their tips. Cingulum and sulcus are present, delineated by faint upraised sutures and alignment of processes; tabulation not otherwise determinable. Archaeopyle apical.

Holotype: Slide L.C.V./1b at 100.1-43.6, Palynological Collection of the Department of Geology, University of Alberta, Edmonton, Canada.

Locality and Horizon: Cobrico Swamp, Victoria, Australia; Holocene.

Fig. 2

Fig. 3

Fig. 2—*Cobricosphaeridium hebes* sp. nov., holotype, showing the nature of the archaeopyle and the general morphology. Orientation unknown; × *c.* 750.
Fig. 3— *C. spiniferum spiniferum* subsp. nov., holotype, oblique ventral view, × *c.* 800.

DIMENSIONS: Holotype: Length 49μ, breadth 47μ, the larger processes range from 4-9μ in length and the small processes all measured 2μ in length. Range: Length 36 (41·7) 49μ, breadth 32 (37·2) 47μ, length of larger processes 4 (7) 11μ, smaller processes from 2 to 3μ. Nine specimens were measured (the total available material).

DESCRIPTION: The spherical to sub-spherical central body is made up of two layers, the periphragm giving rise to all the ornamentation. Total wall thickness of the order of 1μ. There are two distinct process types. The first is conspicuous, and less numerous than the second type; but even so, approximately thirty processes may be counted around the periphery of the holotype. They are very variable in morphology, and appear for the most part randomly disposed, although there is some alignment in the cingular and sulcal regions. It is not clear whether these are to be regarded as sutural or as intratabular processes. (No other indication of the tabulation is present.) These processes are solid and do not connect to the interior of the cyst. The processes of the second type are much smaller, less conspicuous, delicate, solid and having a hair-like appearance. They are very numerous, more than a hundred being seen around the periphery of the holotype. Seen in plan, they give the surface of the cyst a pseudogranular appearance. Sulcus and cingulum are usually not well differentiated; some indication of their presence is given by the alignment of the larger processes and the presence of faint sutures. The amount of offset of the cingulum appears very slight. The archaeopyle, not seen in the holotype, is apical and very similar to that of *C. hebes*, being angular with the same development of slits running out from the angles. No operculum was seen.

REMARKS: This species was well represented in the assemblage and the preservation was always good. It differs from *C. hebes* in the entirely dissimilar nature of its processes.

Cobricosphaeridium spiniferum elegans subsp. nov.

(Pl. 21, fig. 4-5. Fig. 4)

DERIVATION OF NAME: L.: *elegans*, delicate in style, with reference to the long and delicate conspicuous processes.

DIAGNOSIS: A subspecies of *C. spiniferum* in which the conspicuous processes are longer, more flexible and delicate than those of typical specimens of the species.

HOLOTYPE: Slide L.C.V./5a at 105.2-31.7, Palynological Collection of the Department of Geology, University of Alberta, Edmonton, Canada.

LOCALITY AND HORIZON: Cobrico Swamp, Victoria, Australia; Holocene.

DIMENSIONS: Holotype: Length 41μ, breadth 35μ, larger processes from 9-12μ in length and the smaller processes are on average 2μ in length. Range: length 40 (42) 45μ, breadth 32 (35·5) 39μ, length of larger processes 8 (10) 12μ, length of smaller processes range from 1-3μ. Six specimens were measured, the total available material.

DESCRIPTION: Spherical to sub-spherical central body made up of two body layers, the outer giving rise to the ornamentation. Two process types are present. The larger processes are similar to those of *C. spiniferum spiniferum* except that they are longer, more slender, and appear more flexible. The shorter processes are entirely similar in character: cingulum and sulcus are again poorly differentiated. The archaeopyle is apical (A).

REMARKS: This subspecies is quite well represented in the samples and is always readily distinguishable, on the character of its processes. No intermediate forms were encountered. A single differentiating character of such a nature is considered by the authors to be insufficient to justify taxonomic separation at specific level, until a much greater volume of information is available on the range of variation within the species *C. spiniferum*.

Genus **Aquadulcum** gen. nov.

DERIVATION OF NAME: L.: *aqua dulcum*, freshwater, with reference to the habitat in which these cysts were found.

DIAGNOSIS: Peridinoid to sub-spherical proximate cysts bearing a dense ornamentation of very short spines or vermiculae. The cingulum and sulcus are clearly differentiated by lack of such ornament. Nature of archaeopyle uncertain, possibly in the form of a transapical slit; no clear opening is normally visible.

TYPE SPECIES: *Aquadulcum serpens* sp. nov., Holocene, Victoria, Australia.

REMARKS: This new genus is characterized by its shape, the nature of its ornamentation, and the absence of a reflected tabulation. The genera *Tenua* and *Cobricosphaeridium* differ in that they develop a typical apical (A) archaeopyle and *Xenicodinium* in that it possesses a precingular archaeopyle. *Diconodinium* is characterized by its development of apical and antapical horns: the nature of its archaeopyle is uncertain. The cysts of the freshwater dinoflagellate *Peridinium limbatum* (recently described by Evitt and Wall, 1968) are cavate: the type of archaeopyle they exhibit, opening on a transapical suture, may possibly be com-

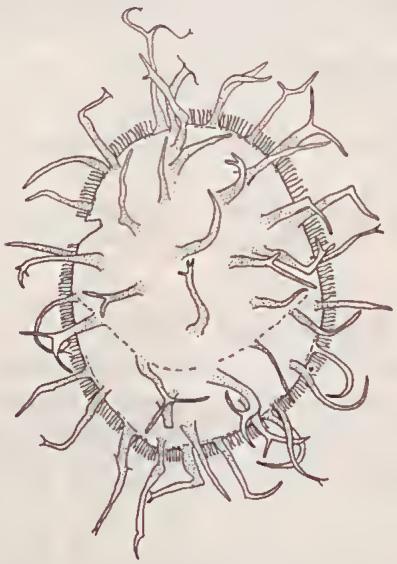

FIG. 4

FIG. 5

FIG. 4—*C. spiniferum elegans* subsp. nov., holotype, showing the general morphology and in particular the nature of the processes. Orientation unknown, × *c.* 1000.
FIG. 5—*Aquadulcum serpens* sp. nov., holotype, in oblique ventral view, × *c.* 750.

parable to that of *Aquadulcum,* but this remains to be confirmed. *Palaeohystrichophora,* which is similar in ornamentation to *Aquadulcum,* is likewise cavate.

Aquadulcum serpens sp. nov.

(Pl. 21, fig. 7-8. Fig. 5)

DERIVATION OF NAME: L.: *serpens,* serpent, referring to the vermiculate nature of the ornament.

DIAGNOSIS: Peridinoid to sub-spherical central body bearing a dense ornamentation of vermiculae. Sulcus and cingulum clearly defined by lack of ornament. The cingulum is offset by an amount equal to half its own width. The archaeopyle was not seen.

HOLOTYPE: Slide L.C.V./7a at 99-39.4, Palynological Collection of the Department of Geology, University of Alberta, Edmonton, Canada.

LOCALITY AND HORIZON: Cobrico Swamp, Victoria, Australia; Holocene.

DIMENSIONS: Holotype: Length 45μ, breadth 37μ, height of vermiculae above central body approximately 1μ. Range: Length 45μ, breadth 34-37μ, height of vermiculae above cyst, less than 1μ to 1μ. Two specimens were measured, the total available material.

DESCRIPTION: The central body is peridinoid to sub-spherical in shape, the epitract being slightly more conical than hypotract. Over the surface of the cyst there is a dense, irregular ornamentation of vermiculae, i.e. upraised ridges that appear 'worm-like' in plan view. (This is the sense as used by the authors.) At low magnifications, this ornamentation appears to exhibit a separation into discrete areas, forming a faint pattern on the surface of the cyst. This pattern does not suggest a reflected tabulation. The sulcus extends to at least three-quarters of the length of the epitract and approximately one-half the length of the hypotract. An offset equal to half the width of the cingulum may be seen across the sulcus. The cyst surface between the vermiculae is smooth and no other form of ornamentation was seen.

The presence of a slight break at the apex of the holotype may be an indication of the development of a transapical archaeopyle, but this remains to be confirmed.

REMARKS: The only species of dinoflagellate cyst yet described which possesses an ornament comparable to that of *A. serpens* is *Tenua verrucosa* Sarjeant 1968; however, the 'verrucae' of the latter species are seen, at high magnification, to be very broad, very short spines with brief branches, thus quite dissimilar to the ornament of *A. serpens;* moreover, an apical ($\bar{A}$) archaeopyle is consistently developed.

The other species now placed in the genus *Aquadulcum* have an ornament of short spines. They are as follow:—

Aquadulcum myalupensis (Churchill and Sarjeant 1963) comb. nov.

Palaeohystrichophora myalupensis. Churchill and Sarjeant 1963, 38-40, figs. 5, 22, 23; Downie and Sarjeant 1964, 136.

DISCUSSION: This species was first described from the Holocene (Sub-Boreal Stage, 3000-500 B.C.) of Myalup Swamp, near Harvey, Western Australia. It has an ellipsoidal shell, with conical epitract and rounded hypotract, bearing an irregular scatter of short spines, simple or with two unequally developed branches.

Spines are absent from eingulum and suleus; the eingulum is extremely broad, planar, the suleus somewhat less broad.

A re-examination of the holotype diselosed no reeognizable archaeopyle. A faint marginal slit was present at the level of the eingulum, but this probably resulted simply from compression.

This species is transferred to the genus *Aquadulcum* on the basis of general form and the absenee of an endoblast (inner body). It is a proximate eyst, apparently eomposed of two wall layers in eontinuous contaet, with the spines arising from the outermost layer only.

The type material is now lodged in the eolleetions of the National Museum of Vietoria, Melbourne, as slides P26437 (holotype) and P26439 (paratype).

Aquaduleum pikei (Churchill and Sarjeant 1963) comb. nov.

Palaeohystrichophora pikei. Churchill and Sarjeant 1963, 40-41, figs. 6, 24; Downie and Sarjeant 1964, 137.

Discussion: This speeies was deseribed from the Holoeene (Sub-Atlantie Stage, 500 B.C. to present day) of Myalup Swamp, near Harvey, Western Australia. It has an ovoidal shell, with rounded conieal epitraet and rounded hypotraet, bearing a dense eover of very short spines, bifureating at a eonstant distanee from the shell surfaee. Spines are absent from eingulum and suleus; the eingulum is narrow, markedly laevo-rotatory, the suleus only slightly broader.

A re-examination of the holotype diselosed no indieation of an arehaeopyle. This speeies is transferred to the genus *Aquadulcum* on the basis of general form and the absenee of an endoblast. It is a proximate eyst, apparently eomposed of two wall layers in continuous eontaet, with the spines arising from the outermost layer only. It differs from *A. myalupensis* in the nature of the spines and in the relative narrowness and markedly helieoidal nature of the eingulum.

The holotype is now lodged in the eolleetions of the National Museum of Vietoria, Melbourne, in slide P26435.

? **Aquadulcum yanehepense** sp. nov.

(Pl. 22, fig. 3)

1963 Organism No. 2. Churchill and Sarjeant, 50, figs. 8, 35.

Derivation of Name: Based on the type locality—Yanehep Swamp, Western Australia.

Diagnosis: Cyst broadly ovoidal in outline, with rounded eonieal epitraet and almost hemispherieal hypotraet. Wall of moderate thiekness, possibly eomposed of a single layer only, markedly granular and giving rise to some sixty short, rather stubby proeesses. The arrangement of the proeesses, along the borders of the eingulum and in lines elsewhere, suggests that they may be sutural in eharaeter. Eaeh proeess tapers from a broad base to about mid-point, then flares to the tips; the proeess tips are braneheđ, the braneheđ being of unequal length, and the braneheđ themselves may bifureate. Their length is up to about one-sixth of the short diameter of the shell.

The eingulum is broad, slightly sunken and devoid of proeesses; it is laevo-rotatory, the two ends differing in antero-posterior position by the eingulum's breadth. The suleus is narrower and rather poorly marked.

An apieal opening was observed in the holotype but was not eonstantly observed in all speeimens.

HOLOTYPE: Specimen Yanchep 310/320/1 of Churchill and Sarjeant (1963, figs. 8, 35): contained in slide P26446, National Museum of Victoria, Melbourne, Australia.

LOCALITY AND HORIZON: Holocene (post-Atlantic, not precisely dated), Yanchep Swamp, north of Perth, Western Australia.

DIMENSIONS: Holotype: Length 52μ, breadth 46μ. Other specimens of closely similar dimensions.

DISCUSSION: These microfossils were originally very tentatively described as 'Organism No. 2', by Churchill and Sarjeant, 1963. Their re-examination affords no room for doubt that these are dinoflagellate cysts.

In the holotype, and in some other specimens, a distinct apical opening was present, in the form of a polygonal, rather elongate slit with a V-shaped end aligned on the sulcus and a corresponding V-shaped end on the dorsal surface. This opening is smaller in size than a typical A apical archaeopyle and quite dissimilar in outline: if it is indeed to be regarded as a form of apical archaeopyle (as seems probable), it may be formed by the loss of the equivalent of plate 1′ and one other apical plate, rather than by the loss of the equivalent of the whole apical plate series.

The generic assignment of this species is problematical: in that only one type of process is present, it differs from the genus *Cobricosphaeridium,* and in the possible development of an apical archaeopyle, it differs from the genus *Aquadulcum*. The character of the apical opening differentiates it from the genus *Tenua* (not hitherto recorded from post-Mesozoic sediments). If more extended studies confirm the constancy of the archaeopyle and its distinctive character (not all specimens originally examined were available for re-study) then the erection of a separate genus may prove desirable.

? **Aquadulcum** cf. **yanchepense** Harland and Sarjeant

(Pl. 21, fig. 9. Fig. 6)

DESCRIPTION: Cyst broadly ovoidal to sub-spherical in outline, with rounded conical epitract and rather flattened hemispherical hypotract. Wall thin, possibly composed of a single layer only, and having a granular surface, from which arise some 70-80 rather short processes. The arrangement of the processes, along the borders of the cingulum and in lines elsewhere on the surface, suggests that they may be sutural in character. The length of the processes is about one-fifth of the short diameter. They have slightly broadened bases; sometimes they taper to mid-point, sometimes they are of relatively constant thickness. Branching may occur from mid-point in the length or at the tips: the branches may be similar or (more frequently) dissimilar in length and may themselves branch or ramify.

The cingulum is broad, poorly marked by absence of processes and by the alignment of processes on its boundary: the sulcus is narrower and very poorly marked. No archaeopyle or similar opening was observed in the specimens examined.

FIGURED SPECIMEN: Slide L.C.V./5b at 104.5-37.9, Palynological Collection of the Department of Geology, University of Alberta, Edmonton, Canada.

LOCALITY AND HORIZON: Cobrico Swamp, Victoria, Australia; Holocene.

DIMENSIONS: Figured specimen: Length 42μ, breadth 42μ, length of processes 3-7μ. Second specimen: Length 54μ, breadth 44μ, length of processes 3-8μ. (Two specimens seen.)

REMARKS: In general morphology, these specimens resemble *Aquadulcum myalupensis,* differing only in details of process structure: it is probable that, when the Australian freshwater assemblages are fully known, they will be considered as representatives, E. & W. on the subcontinent, of a single species—either differing at subspecific level or not at all.

? **Aquadulcum** sp. A.

(Pl. 21, figs. 10, 11. Fig. 7)

DESCRIPTION: Cyst spherical to sub-spherical, with a thin wall composed of two shell layers. The surface of the periphragm lacks granulation or other ornament. The periphragm gives rise to a dense cover of processes, short (approximately one-sixth of the short diameter), slender, erect to curved, cylindrical to tapering, commonly bifid, sometimes with branches of equal or (typically) unequal length. The cingulum is marked by lines of processes: it is broad and slightly laevo-rotatory. The sulcus is extremely poorly marked.

The single specimen seen of this morphological type appears to exhibit an apical opening comparable to that of *A. yanchepense*: however, it is partly obscured by surrounding debris and could not satisfactorily be studied.

FIGURED SPECIMEN: Slide L.C.V./8 at 101.3-31.3, Palynological Collection of the Department of Geology, University of Alberta, Edmonton, Canada.

LOCALITY AND HORIZON: Cobrico Swamp, Victoria, Australia; Holocene.

DIMENSIONS: Figured specimen: Length 43μ, breadth 39μ, process length ranging from 4-7μ.

REMARKS: The single specimen encountered of this morphological type probably represents an undescribed species related to *A. yanchepense.* It is tentatively placed in the genus *Aquadulcum,* in the absence of knowledge of the archaeopyle, on the basis of the relatively dense spine cover and overall shape, the presence of only a single type of process precluding its allocation to *Cobricosphaeridium.*

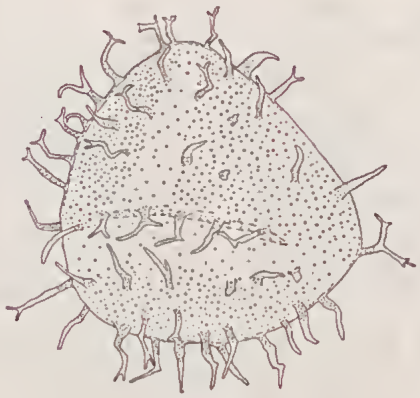

FIG. 6

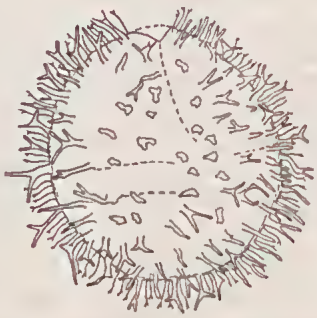

FIG. 7

FIG. 6—? *A* cf. *yanchepense,* in oblique ventral view, × *c.* 900.
FIG. 7—? *A* sp. A., in unknown orientation, × *c.* 950.

Genus **Muiradinium** gen. nov.

DERIVATION OF NAME: Based on the type locality of the type species: West Lake Muir, Western Australia.

DIAGNOSIS: Proximate dinoflagellate cyst, with a thin wall possibly composed of a single layer: no inner body is present. Ambitus diamond to spindle-shaped (varying with aspect), modified by the presence of nipple-like prominences at apex and/or antapex. Surface unornamented or with faint granulations or punctations. Cingulum prominent, marked by a pronounced groove: sulcus very poorly marked. A suggestion of tabulation, by faint lines on the surface, may be present or absent: but a full tabulation is not determinable. Archaeopyle intercalary, small and placed very close to the apex.

TYPE SPECIES: *Muiradinium dorsispirale* (Churchill and Sarjeant, 1963) comb. nov., herein = *Gymnodinium dorsispirale* Churchill and Sarjeant, 1963, pp. 33-34, figs. 2, 18. Holocene, Western Australia.

REMARKS: This new genus differs from the genus *Deflandrea* in the lack of an inner body: from the cysts of *Peridinium limbatum* (recently re-studied by Evitt and Wall, 1968) in the character of its archaeopyle: from the cyst here described as ? *Peridinium diamantum* in the smaller size of the archaeopyle and the absence of a recognizable *Peridinium*-type tabulation: and from the genus *Dinogymnium* Evitt, Clarke and Verdier 1967 in the character of the archaeopyle and the absence of any system of mural pores.

The identity of the dinoflagellate which formed this cyst remains a matter for speculation. The outline resembles that of some members of the Order Gymnodiniales, four genera of which *(Amphidinium, Gymnodinium, Gyrodinium* and *Massartia)* are known from fresh water: but the shape of the archaeopyle and the occasional faint suggestions of a tabulation favour the possibility that this is the cyst of a freshwater member of the Family Peridiniaceae and probably of a species of the genus *Peridinium* (much the most abundant genus in fresh waters). This genus does contain biconical species: recent studies have suggested that, though its motile morphology is relatively constant, the morphology of its cysts is very variable and a future division of the genus into a number of new genera, on the basis of knowledge of the whole life cycle, seems probable.

Muiradinium dorsipirale (Churchill and Sarjeant 1963) comb. nov., emend.

(Pl. 22, fig. 4-5)

Cyanophyceae. Churchill 1960, 493, fig. 1, no. 4.
Gymnodinium dorsispirale. Churchill and Sarjeant 1963, 33-34, figs. 2, 18; Downie and Sarjeant 1964, 116; Evitt, Clarke and Verdier 1967, 6.

EMENDED DIAGNOSIS: Proximate cyst with a test whose ambitus may be diamond to spindle-shaped according to aspect. A nipple-like prominence is present at the apex, sometimes also at the antapex. The shell surface is densely but finely granular: occasionally it bears faint lines indicative of a reflected tabulation. The cingulum is well marked, deeply hollowed and bordered by raised ridges. It is slightly laevo-rotatory and sometimes exhibits transverse striations. The sulcus is poorly marked, broad at mid-point but narrowing towards apex and antapex. A small angular intercalary archaeopyle is present immediately below the apex: it appears formed by the loss of the equivalent of a single intercalary plate or of two very small plates.

HOLOTYPE: Specimen West Muir 30.40/2, now lodged in the collections of the National Museum of Victoria, Melbourne, in slide P26436.

DIMENSIONS: Holotype: Length 51μ, breadth 39·5μ. Observed range: Length 45-60μ.

REMARKS: This species was originally described from the Holocene (Atlantic Stage, 5000-3000 B.C.) of West Lake Muir, Western Australia. The assumption that this was a fossil motile dinoflagellate, which caused its assignation to the genus *Gymnodinium*, is certainly incorrect: on the one hand, because it is now considered that the remains of motile dinoflagellate thecae are incapable of fossilization, and on the other hand, because re-examination of the type material has shown an 'exit-hole', an archaeopyle, to be constantly present. Evitt, Clarke and Verdier (1967), in a re-study of the fossil species placed in the genus *Gymnodinium* which led to the erection of the genus *Dinogymnium* to accommodate Cretaceous forms, noted that *Gymnodinium dorsispirale* did not appear attributable to that genus. Re-study of the type material entirely confirms their conclusion, for the West Australian forms have an archaeopyle of dissimilar type and lack the system of mural pores characteristic of *Dinogymnium*.

The apparent torsion of the cingulum at dorsal mid-point, present in many specimens (though not in all), is most probably a distortional effect produced during diagenesis (cf. Fig. 4 of Evitt, Clarke and Verdier) and has accordingly not been mentioned in the revised diagnosis of the species.

Genus **Peridinium** Ehrenberg 1832

? **Peridinium diamantum** Churchill and Sarjeant 1963

(Pl. 22, fig. 2)

? *Peridinium diamantum*. Churchill and Sarjeant 1963, 34, 36, figs. 3, 19; Downie and Sarjeant 1964, 139.

REMARKS: This species was originally described from the Holocene (Atlantic Stage, 5000-3000 B.C.) of West Lake Muir, Western Australia. This is certainly a cyst, the presence of an opening in the epitheca being noted in the original description. A re-study of the holotype and of some other specimens confirms this to be an intercalary plate (2I, in the notation of Evitt, 1967). No inner body is present: it was not possible to determine whether the cyst was composed of a single wall layer or of two layers.

The nature of the (incompletely determined) tabulation and the character of the archaeopyle combine to indicate that this is a cyst of a freshwater member of the Family Peridiniaceae of, probably, a species of the genus *Peridinium* (much the most abundant in fresh waters) itself. The taxonomy of this genus must shortly be overhauled, in view of the realization that similar motile forms may have markedly dissimilar cysts and are thus the product of different evolutionary lineages: until this is done, it is considered that the species *P. diamantum* is best left within the genus *Peridinium*.

The holotype is now lodged in the collections of the National Museum of Victoria, Melbourne, in slide P26436.

Genus **Muiriella** (Churchill & Sarjeant 1963), emend.

(Fig. 8)

Muiriella. Churchill and Sarjeant 1963, 36-7; Downie and Sarjeant 1964, 134; Norris and Sarjeant 1965, 42.

Muiriella plioplax. Churchill and Sarjeant 1963, 37-8, figs. 4, 20, 21; Loeblich and Loeblich 1966, 41.

EMENDED DIAGNOSIS: Proximate dinoflagellate cyst of spherical to ovoidal shape, with the tabulation ?′, 3a, 6-?7″, ?6c, 8‴, 2p, 4p.e., I⁗, 3-?4s. Archaeopyle apical.

TYPE SPECIES: *Muiriella plioplax* Churchill and Sarjeant, 1963, emend. Harland and Sarjeant, herein: Holocene, Western Australia.

REMARKS: A re-study of the holotype of the type species showed that what was originally considered damage at the antapex was, in fact, an archaeopyle. Since, in all cases studied to date, the archaeopyle of a dinoflagellate cyst is developed by loss of plates from the epitract, it was realized that the tabulation, as originally reconstructed, was inverted. This is here corrected and a revised diagnosis is accordingly formulated.

Muiriella plioplax (Churchill and Sarjeant (1963), emend nov.
(Fig. 8)

Muiriella plioplax. Churchill and Sarjeant 1963, 37-8, figs. 4, 20, 21; Vozzhennikova 1963, 171-186. Downie and Sarjeant 1964, 134; Norris and Sarjeant 1965, 42; Loeblich and Loeblich 1966, 41.

EMENDED DIAGNOSIS: A species of *Muiriella* having a roughly spherical test, with epitract and hypotract each forming a hemisphere. Cingulum of moderate breadth, laevo-rotatory: sulcus slightly broader, widening in its hypotractal portion, subdivided into three (or four) sections by transverse crests. Low crests define the tabulation; these give rise to short spines, commonly simple but sometimes with bi- or trifurcate terminations. The relative length and spacing of the crest spines is variable. The apex is typically lost in archaeopyle formation. The posterior surface is occupied by a group of small plates, here considered to fall into two distinct groups arranged about a single antapical plate.

HOLOTYPE: Specimen South Muir 0-10/1, peat at 0-10 cm. depth (late Atlantic Stages, 2500-3000 B.C.) South Muir, N. of Walpole, Western Australia. Now lodged in the collections of the National Museum of Victoria, Melbourne, as slide P26438.

DIMENSIONS: Holotype: Length 52·5μ, breadth 53·5μ, spines 3-5μ in length. Other specimens comparable. (12 specimens.)

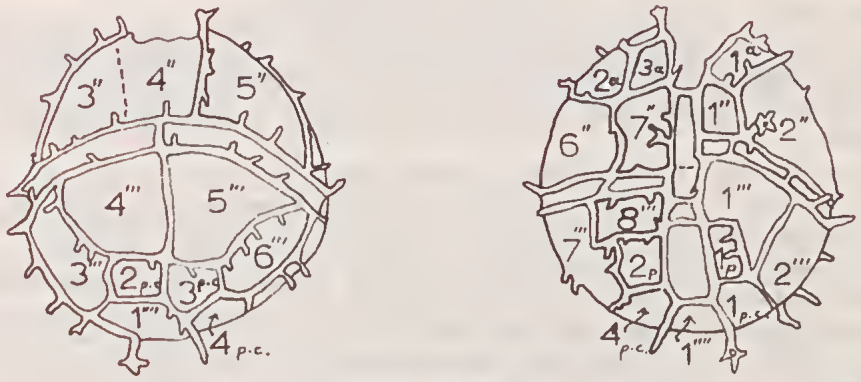

FIG. 8—*Muiriella plioplax* (Churchill and Sarjeant, 1963), emend., holotype, West Muir 30.40/2. Left: in oblique dorsal view. Right: in oblique ventral view. × *c.* 800.

DESCRIPTION: The condition, not only of the holotype but also of the other specimens contained in slide P26438, has markedly deteriorated in the period since the first study was made: the specimens appear to have contracted and folded, and it proved impossible to reconfirm all details originally observed. Fig. 8 is therefore based in part on the original sketches, in part on the new observations: the description is a revised restatement of the earlier description.

Shell yellowish brown, not (or only very minutely) granular. Apex lost in archaeopyle formation. Three anterior intercalary plates are present, situated on either side of the cingulum. Six or seven precingular plates are present, the boundary between plates 3″ and 4″ being obscured (if present). Plate 1″ is markedly reduced, plates 6″ and 7″ to a lesser degree, to accommodate the anterior intercalary plates.

The cingulum forms a laevo-rotatory spiral such that its two ends differ in antero-posterior position by the furrow's width: it is subdivided into at least six cingular plates. The sulcus is divided into three or four plates by transverse crests.

Eight postcingular plates were recognized, with plate 8‴ reduced to accommodate plate 2p. A cluster of small plates surrounds the antapex.

The crests delimiting plates and furrow boundaries have the form of low ridges, from which arise strong, short processes. These processes typically have closed tips, but in at least two instances on the holotype, they appear to take the form of tubes open distally.

REMARKS: The large number of plates and the not particularly characteristic shape combine to make the relation of this cyst to any particular motile dinoflagellate genus a matter for speculation. The deterioration of the type material is regrettable: it may result from partial drying out of the mountant. The specimens from Myalup, Western Australia (mentioned in the original description) were not available for re-study.

Group ACRITARCHA Evitt
Subgroup ACANTHOMORPHITAE Downie, Evitt & Sarjeant 1963

Genus **Creberlumectum** gen. nov.

DERIVATION OF NAME: L.: *creber,* thick, dense; *lumectum,* thorn-thicket, in reference to the spine cover characteristic of this genus.

DIAGNOSIS: Acritarchs of ovoidal to ellipsoidal shape, with processes distributed generally, and without arrangement, over the shell surface, typically short and of variable character. Shell surface smooth, granular or punctate: shell wall typically or constantly two-layered. No archaeopyle or other opening has been recognized.

TYPE SPECIES: *Creberlumectum telmaticum* (Churchill and Sarjeant, 1963) Harland and Sarjeant, comb. nov., herein = *Baltisphaeridium telmaticum* Churchill and Sarjeant, 1963, pp. 44-5, Figs. 13, 32. Holocene, Western Australia.

REMARKS: The group of elongate, spinose species from Western Australia remain of uncertain affinity, but their morphology does not accord with the revised diagnosis of the genus *Baltisphaeridium* proposed by Staplin, Jansonius and Pocock (1965), nor do they fall within the compass of the other genera formulated by those authors. Accordingly, a new genus is here proposed, defined by the shell shape and the absence of any form of opening.

Creberlumectum telmaticum (Churchill and Sarjeant 1963) comb. nov.

Baltisphaeridium telmaticum. Churchill and Sarjeant 1963, 44-5, figs. 13, 32; Downie and Sarjeant 1964, 97.

REMARKS: The holotype is now lodged in the collections of the National Museum of Victoria, Melbourne, as slide P26444. The specimen figured as *Baltisphaeridium* cf. *telmaticum* (now *Creberlumectum* cf. *telmaticum*) is similarly lodged, in slide P26443.

Creberlumectum tinglewoodense (Churchill and Sarjeant 1963) comb. nov.

Baltisphaeridium tinglewoodense. Churchill and Sarjeant 1963, 42-4, figs. 12, 29; Downie and Sarjeant 1964, 97.

REMARKS: The holotype is now lodged in the collections of the National Museum of Victoria, Melbourne, as slide P26440.

Creberlumectum clavispinulosum (Churchill and Sarjeant 1963) comb. nov.

Baltisphaeridium clavispinulosum. Churchill and Sarjeant 1963, 41-2, figs. 14, 31; Downie and Sarjeant 1964, 88.

REMARKS: The split in the wall of the holotype appears more like random damage (resulting from compression?) than a preformed opening: not all specimens showed such a split. The holotype is now lodged in the collections of the National Museum of Victoria, Melbourne, as slide P26442.

Creberlumectum quaternarium (Churchill and Sarjeant 1963) comb. nov.

Baltisphaeridium quaternarium. Churchill and Sarjeant 1963, 46-7, figs. 16, 33; Downie and Sarjeant 1964, 95.

REMARKS: The holotype is now lodged in the collections of the National Museum of Victoria, Melbourne, in slide P26441.

Creberlumectum echiniplax (Churchill and Sarjeant 1963) comb. nov.

Baltisphaeridium echiniplax. Churchill and Sarjeant 1963, 46, figs. 11, 26; Downie and Sarjeant 1964, 89.

REMARKS: The holotype (whose condition has markedly deteriorated) is now lodged in the collections of the National Museum of Victoria, Melbourne, in slide P26439.

? **Creberlumectum** sp. A.

? *Baltisphaeridium* sp. A. Churchill and Sarjeant 1963, 47-8, figs. 9, 27.

REMARKS: The possession of a circular terminal opening in the unique specimen renders this attribution dubious. The specimen is now lodged in the collections of the National Museum of Victoria, Melbourne, in slide P26445.

? **Creberlumectum** sp. B.

Baltisphaeridium sp. B. Churchill and Sarjeant 1963, 48, figs. 15, 28.

REMARKS: The spherical to subquadrate shell shape of this specimen renders its attribution to *Creberlumectum* inappropriate: but it is considered better placed in a genus known from non-marine Quaternary sediments than in one that is exclusively marine and not confidently recorded from post-Mesozoic sediments. Undoubtedly transfer to another genus will ultimately prove necessary. The figured specimen is now lodged in the collections of the National Museum of Victoria, Melbourne, in slide P26443.

Creberlumectum sp. C.

Baltisphaeridium sp. C. Churchill and Sarjeant 1963, 49, figs. 17, 30.

REMARKS: The unique specimen is now lodged in the collections of the National Museum of Victoria, Melbourne, in slide P26444.

Incertae Sedis

Organism No. 1

Organism No. 1. Churchill and Sarjeant 1963, 49-50, figs. 7, 25.

REMARKS: The affinities of this form remain obscure. The figured specimen is now lodged in the collections of the National Museum of Victoria, Melbourne, in slide P26443.

Conclusions

This paper has described three new genera and four new species of dinoflagellate cysts together with one new acritarch genus, all from freshwater deposits in Australia. The taxonomy, as presented here, results from a study of new material from Victoria and a re-appraisal of material already described from South-Western Australia by Churchill and Sarjeant (op. cit.).

A brief introduction has been given to the geological setting of the deposits at Cobrico Swamp, Victoria, earlier in this paper. Table 1 (below) shows the distribution of samples; depth, within the peat, at which they were taken; and the number of dinoflagellate cysts observed in each slide.

TABLE 1

Slide No.	Depth in cm.	Code No.	No. of Microplankton
20	150	LCV/1	1
21	150	LCV/1	1
27	170	LCV/2	1
28	180	LCV/3	1
60	260	LCV/4	1
79	320	LCV/5	4
80	320	LCV/5	3
81	320	LCV/5	4
85	340	LCV/6	7
86	340	LCV/6	8
88	350	LCV/7	6
90	350	LCV/7	4
94	360	LCV/8	5
100	380	LCV/9	8

Dinoflagellate cysts make up less than 1% of the total palynomorph population in all cases. Fig. 9 is an attempt to show the distribution of the dinoflagellate cysts within the peat deposit and to graph the number of cysts observed in each slide. It may be seen that a peak is reached at 340 cm. depth in both numbers and variety of cysts. No significance can be given to this observation as it could easily be a result of a preservation effect or a sample bias, especially in the light of the numbers of cysts present. Further study alone will reveal whether some kind of zonation could be developed for deposits such as these, but for the moment the authors feel obliged only to tabulate the results, and reserve comment.

It is hoped, however, that this paper has brought some perspective to this particular field of dinoflagellate study, and we look forward to its continuing development.

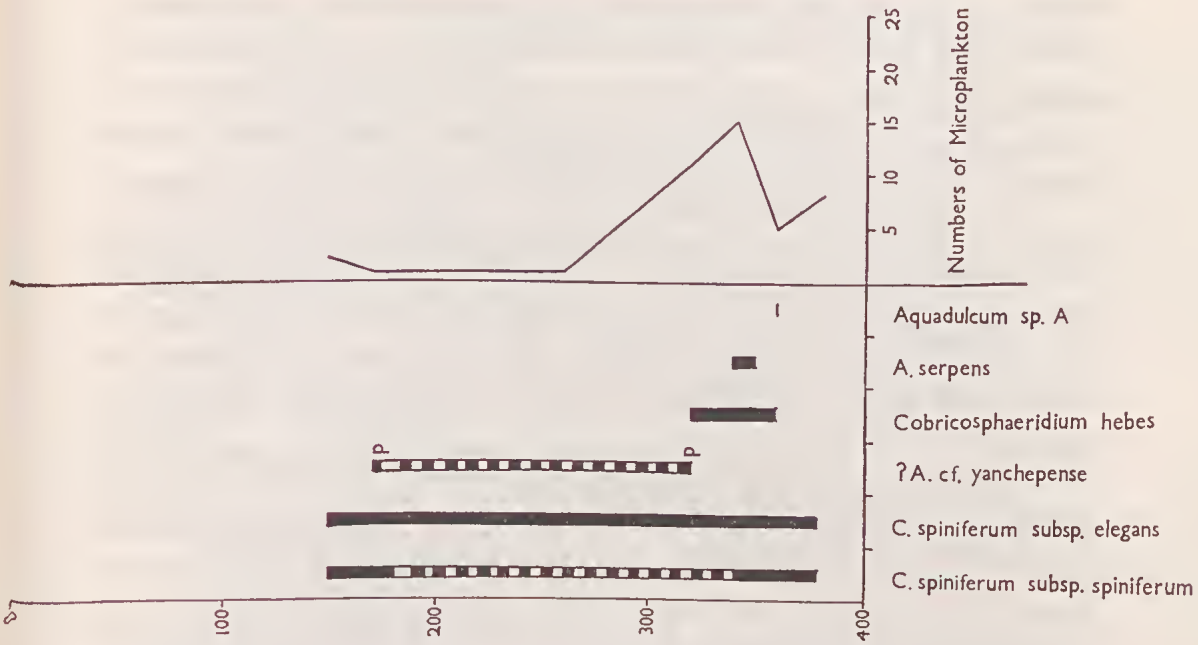

FIG. 9—Distribution table of microplankton at Cobrico Swamp; solid line indicates presence, checks indicate probable range and 'p' indicates presence where not possible to indicate otherwise. Frequency of microplankton in relation to depth is also depicted.

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References

BAKER, H., 1753. Of luminous water insects, in R. DODSLEY, *Employment for the Microscope*. London. 399-403.

BRADLEY, W. H., 1931. Origin and microfossils of the oil shales of the Green River Formation of Colorado and Utah. *U.S. Geol. Surv. Prof. Paper* 168: I-VI + 1-58, 28 pl.

BURSA, A., 1958. The Freshwater Dinoflagellate *Woloszynskia limnetica* n. sp. Membrane and Protoplasmic Structures. *J. Protozool.* 5: 299-304.

CHURCHILL, D. M., 1960. Living and Fossil Unicellular Algae and Aplanospores. *Nature.* 186: 493-494.

————, & SARJEANT, W. A. S., 1962. Fossil Dinoflagellates and Hystrichospheres in Australian Freshwater Deposits. *Ibid.* 194: 1094.

————, & ————, 1963. Freshwater Microplankton from Flandrian (Holocene) Peats of South Western Australia. *Grana Palynol.* 3: 29-53.

COOKSON, I. C., 1953. Records of the Occurrence of *Botryococcus braunii*, *Pediastrum* and the Hystrichosphaeridae in Cainozoic Deposits of Australia. *Mem. nat. Mus. Vict.* 18: 107-123.

CRIDLAND, A. A., 1957. A Note on Two Freshwater Dinoflagellates. *New Phytol.* 57: 285-287.

DAVEY, R. J., DOWNIE, C., SARJEANT, W. A. S., & WILLIAMS, G. L., 1966. Studies on Mesozoic and Cainozoic Dinoflagellate Cysts. *Bull. Brit. Mus. (Nat. Hist.) Geology.* 3: 1-248.

DOWNIE, C., & SARJEANT, W. A. S., 1964. Bibliography and Index of Fossil Dinoflagellates and Acritarchs. *Geol. Soc. Am. Mem.* 94: 1-180.

————, EVITT, W. R., & SARJEANT, W. A. S., 1966. Dinoflagellates, Hystrichospheres and the Classification of the Acritarchs. *Stanford. Univ. Publs. Geol. Sci.* VII: No. 3, 1-16.

EDDY, E., 1930. The Freshwater Armored or Thecate Dinoflagellates. *Trans. Am. microscop. Soc.* 4: 277-321.

EHRENBERG, C. G., 1838. Über das Massenverhältnis der jetzt lebenden Kieselinfusorien und über ein neues Infusorien-Conglomerat als Polierschiefer von Jastraba in Ungarn. *Akad. Wiss. Berlin.* (1836). 1: 109-135.

EISENACK, A., & FRIES, M., 1965. *Peridinium limbatum* (Stokes) vergleichen mit der Tertiären *Deflandrea phosphoritica* Eisenack. *Geol. Fören. Stockh., Förh.* 87: 239-248.

EVITT, W. R., 1967. Dinoflagellate Studies II. The Archeopyle. *Stanford Univ. Publs. Geol. Sci.* X. No. 3, 1-83.

————, CLARKE, R. F. A., & VERDIER, J. P., 1967. Dinoflagellate Studies III. *Dinogymnium acuminatum* n. gen., n. sp. (Maastrichtian) and other fossils formerly referable to *Gymnodinium* Stein. *Stanford Univ. Publs. Geol. Sci.* X. No. 4, 1-27.

————, & WALL, D., 1968. Dinoflagellate Studies IV. Theca and Cyst of Recent Freshwater *Peridinium limbatum* (Stokes) Lemmermann. *Stanford Univ. Publs. Geol. Sci.* XII. No. 2, 1-15.

FAIRBRIDGE, R. W., 1958. Dating the Latest Movements of the Quaternary Sea Level. *N.Y. Acad. Sci. Trans.* Ser. 2. 20: 471-482.

GODWIN, H., 1966. Introductory Address. Symposium on World Climate from 8000 to 0, B.C. *Roy. Meteorol. Soc. London.* 3-14.

HARRIS, T. M., 1939. A Contribution to the knowledge of the British Freshwater Dinoflagellata. *Proc. Linn. Soc. London.* Session 152. 1: 4-32.

HARRIS, W. F., 1959. Pollen-bearing deposits and forest history. *Proc. N.Z. Ecol. Soc.* No. 6, 46-48.

HUTCHINSON, G. E., 1967. *A Treatise on Limnology. Volume II. Introduction to Lake Biology and the Limnoplankton.* 1st Ed., New York: Wiley.

KOFOID, C. A., 1907. The Plates of *Ceratium* with a note on the unity of the genus. *Zool. Anz.* 32: 177-183.

————, 1908. Exuviation, Autotomy and Regeneration in *Ceratium*. *Univ. Calif. Publs. Zool.* 4: 345-386.

————, 1909. On *Peridinium steini* Jörgensen, with a note on the nomenclature of the skeleton of the Peridinidae. *Arch. Protistenk.* 16: 25-47.

————, 1911. Dinoflagellates of the San Diego Region—IV. The genus *Gonyaulax* with notes on its skeletal morphology and a discussion of its generic and specific characters. *Univ. Calif. Publs. Zool.* 8: 187-269.

————, & SWEZY, O., 1921. The Free-living Unarmored Dinoflagellata. *Mem. Univ. Calif.* 5: 1-538.

KRUTZSCH, W., 1962. Die Mikroflora der Geiseltalbraunkohle III. Süsswasserdinoflagellaten aus subäquatorisch gebildeten Blätterkohlenlagen des mittleren Geiseltales. *Hallesches Jb. Mitteldeutsch. Erdgesch.* 4: 40-45.

LEMMERMANN, E., 1900. Beiträge zur Kenntnis der Planktonalgen. VIII. Peridinialcs aquae dulcis et sub-marinae. *Hedwigia* 39: 115-121.

————, 1902. Bericht der Commission für die Flora von Deutschland. VIII. Peridiniales. *Ber. Deutsch. Bot. Ges.* 20: 257-263.

————, 1910. Algen I (Schizophyceen, Flagellaten, Peridineen), in *Kryptogamenflora der Mark Brandenburg.* Leipzig. 563-682.

LEONARD, A. B., 1955. Rinvenimento di Hystrichosphaeridae in depositi fluviali del Quaternario. *Giorn. Geol. Bologna.* 26: 155-158.
LINDEMANN, E., 1919. Untersuchungen über Süsswasserperidincen und ihre Variationsformen. *Arch. Protistenk.* 39: 209-262.
————, 1925. Klasse: Dinoflagellatae. From EYFERTH-SCHOENICHEN (Ed.), *Einfachste Lebensformen.* Berlin. 144-195.
————, 1928. Peridineae. In A. ENGLER & K. PRANTL (Eds.), *Die Natürlichen Pflanzenfamilien.* Bd. 2, 1-104. Leipzig: Engelmann.
LOEBLICH, A. R. Jr., & LOEBLICH, A. R. III., 1966. Index to the Genera, Subgenera, and Sections of the Pyrrhophyta. *Stud. Trop. Oceanogr. Miami.* 3: 1-94.
MACKÓ, S., 1957. Lower Miocene pollen flora from the valley of Klodnicka near Gliwice (Upper Silesia). *Soc. Sci. Wroclaw. Trav.* 13: 88, 1-313.
MAPLETOFT, H., MONTGOMERY, M., WATERS, J., & WELL, P., 1966. A New Freshwater Dinoflagellate. *New. Phytol.* 65: 54-58.
MÜLLER, O. F., 1773. Vermium terrestrium et fluviatilum seu animalium infusoriorum, helminthicorum et testaceourum, non marinorum secincta historia. Hcineck et Faber typis Martini Hallager, Havniae et Lipsiae. I. 32 pages.
NORRIS, G., & SARJEANT, W. A. S., 1965. A Descriptive Index of Genera of Fossil Dinophyceae and Acritarcha. *N.Z. Geol. Surv. Paleont. Bull.* 40: 1-72.
PLAYFAIR, G. I., 1912. Plankton of the Sydney Water Supply. *Proc. Linn. Soc. N.S.W.* 37: 512-552.
PRESCOTT, G. W., 1928. The Motile Algae of Iowa. *Univ. Iowa Stud., nat. Hist.* 12: 5-40.
RUSSELL, R. J., 1963. Recent Recession of Tropical Cliffy Coasts. *Science.* 139: 9-15.
SARJEANT, W. A. S., 1967. The Xanthidia—The Solving of a Palaeontological Problem. *Mercian Geologist.* 2: 245-266.
————, 1968. Microplankton from the Upper Callovian and Lower Oxfordian of Normandy. *Rev. Micropaléont.* 10: 221-242.
————, & DOWNIE, C., 1966. The Classification of Dinoflagellate Cysts above Generic Level. *Grana Palynol.* 6: 503-527.
————, & STRACHAN, I., 1968. Freshwater Acritarchs in Pleistocene peats from Staffordshire, England. *Ibid.* 8: 204-209.
SCHILLING, A. J., 1891. Die Süsswasser—Peridineen. *Flora. Allg. Bot. Zeit.* 74: 220-299.
————, 1913. Dinoflagellatae, in A. PASCHER (Ed.), *Die Süsswasserflora Deutschlands, Osterreichs und der Schweiz.* Jena 3: 1-66.
SMITH, G. M., 1950. *The Freshwater Algae of the United States.* 2nd ed. 1-719. New York: McGraw-Hill.
STAPLIN, F. L., JANSONIUS, J., & POCOCK, S. A. J., 1965. Evaluation of some Acritarchous Hystrichosphere Genera. *N. Jb. Geol. Paläont. Abh.* 123: 167-201.
THIERGART, F., 1942. Mikropaläobotanische Mitteilungen 3: Uber ein Austreten von Hystrichosphaeridcen in der unter miozänen Braunkohle von Finkenheerd bei Frankfurt a. O. *Reichsst. Bodenforsch. Jb.* 62: 113-116.
THOMPSON, R. H., 1947. Freshwater Dinoflagellates of Maryland. *Contr. Chesapeake. Biol. Lab.* 67: 3-24.
————, 1950. A new genus and new records of freshwater Pyrrhophyta in the Desmokontae and Dinophyceae. *Lloydia* 13: 277-299.
TRAVERSE, A., 1955. Pollen analysis of the Brandon Lignite of Vermont. *U.S. Dept. Interior. Bur. Min. Rept.* 5151: 1-107.
VARMA, C. P., 1964. Do Dinoflagellates and Hystrichosphacrids occur in Freshwater Sediments? *Grana Palynol.* 5: 124-128.
VOZZHENNIKOVA, T. F., 1963. Tip Pyrrophyta. Pirrofitovye vodorosli. Klass Peridineae (Dinoflagellateae). Peridinei, ili Dinoflagellaty. *Osnovy Paleontologii,* 171-186, Moscow. Izdatel. Akad. Nauk. S.S.S.R.
WEST, G. S., 1906. Report on the Freshwater Algae including Phytoplankton of the third Tanganyika Expedition conducted by Dr. W. A. Cunnington. *Linn. Soc. Jour. Bot.* 38: 81-194.
————, 1909. A biological investigation of the Peridiniae of Sutton Park, Warwickshire. *New Phytol.* 8: 181-196.
————, 1916. *Algae.* Vol. I. 1st ed. 49-82. Cambridge Univ. Press.
————, & WEST, W., 1905. A further contribution to the freshwater plankton of the Scottish lochs. *Trans. roy. Soc. Edin.* 41: 477-518.
WOLOSZYNSKA, J., 1917. Beitrag zur Kenntnis der Algenflora Litauens. *Bull. Acad. Sci. Cracovie.* B: 123-130.
————, 1925. Beitrag zur Kenntnis der Süsswasser—Dinoflagellaten Polens. *Acta Soc. Bot. Poloniae.* 2: 1-4.

————, 1929. Dinoflagellatae der polnischen Ostsee sowie der an Piasnica Gelegnen Sümfe. *Arch. d'Hydrobiol. et d'Ichthyol.* 3: 153-277.
ZEUNER, F. E., 1958. *Dating the Past.* 4th ed. 1-516. London: Methuen.

Explanation of Plates

PLATE 21

All figures at × 750 magnification unless otherwise stated.

Fig. 1—*Cobricosphaeridium hebes* sp. nov., holotype, showing the well defined apical archaeopyle and the nature of the test ornamentation.
Fig. 2—*C. hebes* sp. nov., holotype, again showing the archaeopyle and the nature of the ornamentation.
Fig. 3—*C. spiniferum spiniferum* subsp. nov., holotype.
Fig. 4—*C. spiniferum elegans* subsp. nov., holotype, showing the nature of the delicate processes and surface ornamentation.
Fig. 5—*C. spiniferum elegans* subsp. nov., holotype.
Fig. 6—*C. spiniferum spiniferum* subsp. nov., holotype, showing the two distinct process types that are characteristic of the genus, × 2000.
Fig. 7—*Aquadulcum serpens* sp. nov., holotype, showing the sulcus, cingulum and general morphology.
Fig. 8—*A. serpens* sp. nov., holotype, showing the vermiculate ornamentation.
Fig. 9—? *A.* cf. *yanchepense*, showing the general cyst morphology.
Fig. 10—? *A.* sp. A., showing the general morphology.
Fig. 11—? *A.* sp. A., showing the nature of the cingulum.

PLATE 22

All figures at × *c.* 1150 magnification.

Fig. 1—*Muiriella plioplax* (Churchill and Sarjeant,), emend. The holotype (now in poor condition), showing the apical archaeopyle.
Fig. 2—? *Peridinium diamantum* (Churchill and Sarjeant). The holotype, showing the two-plate intercalary archaeopyle.
Fig. 3—? *Aquadulcum yanchepense* sp. nov. The holotype, showing the apical opening.
Fig. 4—*Muiradinium dorsispirale* (Churchill and Sarjeant), comb. nov. A paratype, showing the small intercalary opening.
Fig. 5—*Muiradinium dorsispirale* (Churchill and Sarjeant), comb. nov. To show the form of the cingulum and the tabulation traces.